11 ealth Care Robotics: A Progress Report

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Abstract

This paper describes the app oach followed in **the** *design of a service robot for health care (1)) lica tions. Under the auspices of the NA SA Technology Transfer* **1'111.(/1(11/1,** *a partnership was established between JPL and R WI, o manufacturer of mobile robo ts, to design and evaluate a mobile robo t for health car (assistance to th e elderly and the handicappe d. The main emphasis of the first phase of the project is on the development on* **o** *multi- modal operator int erface* **o11(1** *its eva lua tion by health care pr ofession als and users. This paper d escribes the architectur* **c** *of the system, the* **(W11-7((11?07!** *method* **71,$(** *[], and sonne preliminary results of the user evaluation.*

1 Introduction

In May 1993, the National Aeronautics and Space Administration (NASA) initiated a program of Technology Cooperation Agreements (J ' C A) aimed at transfer ring some of the technologies developed at NASA centers to industrial partners. In Febru ary 1996, the Jet Propulsion 1 aboratory ((11' 1,) developed a TCA with Real World Int er face, Inc. (RWI) to transfer some of its robotics technology into RWI line of mobile robots.

RWI is a leading manufacturer of mobile robots arid has expressed a strong interest in upgrading its product line with an articulated mechanical manipulator and an advanced operator interface. J] '], has a long track record of R&D in the areas of manip ulator contr ol and oper ator int er faces. Researchers at JJ '1 , have developed **C.olit101** schemes for dexterous manipulators [16], mobile robots [9], and mobile manipulators [17]. Furthermore, advanced operato r interface has been an area of active research at J]'], for a decade, in part icula r, for com mand ent ry and data display, time delay compensation, high-fidelity calibration, and performance monitoring [8].

This paper presents a progress report on the cooperation between JPL and RWI for the development of a prototype *service robot* for health care applications.

2 Background

Service robotics is an area of research and development of increasing importance because of its potential scientific, economic, and social payoffs [15]. This area includes robotic systems for tasks outside the industrial manufacturing arena, such as robots for sewers and electrical power tunnels inspection, robots for harvesting, construction robots, and health care robots. Technical challenges of service robotics are the unstructured environment of the applications, system reliability and serviceability, and autonomy during unsupervised operation. These robots will perform tasks that are too dangerous or demanding for humans, thus becoming tools for improving productivity and safety, rather than competitors in the workplace.

Among the many areas of service robotics, health care for assistance to the elderly and the handicapped is the one having the most promising potential. The current trend towards long-term care at home instead of in hospitals and in convalescent homes, and the reduction in medical staff in all health care organizations makes the development of new, advanced tools for medical assistance particularly timely.

This need has not gone unnoticed, and several research projects in medical robotics are pursued by academia and industry. In [6], the first commercial version of a delivery robot for hospital is described. It consists of a sensorized platform capable of unsupervised navigation in medical environments, equipped with beacons and visual markers. In [2], a prototype of a Mobile Robotic Unit for assistance to the disabled is described. This device consists of a mobile platform equipped with a dexterous manipulator, a stereo-camera and a sonar ring. The control is performed by a supervisory system connected to a graphical user interface. This system is currently being converted into a prototype suitable for testing in realistic environments. A concept of automatic medical support is described in [14], where the robotic device is the hospital room itself, equipped with sensors and actuators for recognizing, interpreting and acting upon the needs of the assisted person. Guiding principles for the design of assistive robotic systems are proposed in [10] and include the use of motion and voice commands for the robot, a distributed architecture of simple and robust devices, and enough intelligence to tolerate ambiguity and to cooperate with the user.

It was noticed in *[4]* that the involvement of potential users is one of the critical factors for the successful creation and utilization of a new technology. Particularly for the class of devices addressed by this paper, i.e. robotic system for the assistance to the elderly and the handicapped, the designers have little or no first hand experience of real user needs, and there are serious health implications if the product is improperly designed. To overcome this difficulty, a method was devised for developing an effective cooperation between designers and users [5, 18]. The method consists of including potential users in the design team, and requiring periodic evaluation of the product by multidisciplinary teams. Tasks are defined by users to suit their needs, and then the evaluation team works with the system and the user to see if the tasks can be accomplished, and if not, for what reasons.

In the case of robotics for health services, the discrepancies among technically trained developers, health professionals and patients is large. Health care technologies have often been inappropriate for the people for whom they are designed. In robotics in particular, end-users are often included *after the fact*, and the engineering aspects of the technology take precedence over medical and patient acceptance aspects. In the project described in this paper, we decided to involve the user community from the very beginning of the design, to receive feedback, to test and evaluate the design, and to modify the design based on user feedback.

It must also be noted that the user community consists of several distinct groups, each with specific needs and different expectations from the same health care robot. For example, the health professionals would use the robot as a tool for demanding and repetitive tasks. The support community, consisting of relatives and cognitive intact elderly and the handicapped, would use the robot as an assistant to perform generic, mostly non-medical, tasks. Finally bed-ridden mobility limited people would use the health care robot for their activities of daily life (ADL).

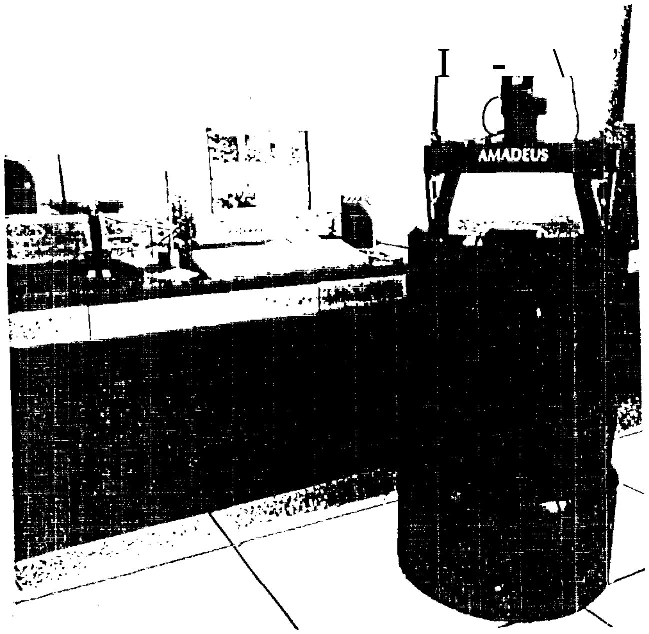

Figure 1: The Health Care Robotic system.

This wide range of possible applications and users make the design of a robotic system for health care very difficult. To overcome this difficulty, we chose to develop a set of functions that can be selected depending on the specific task and user, and let the user, via an interactive evaluation process, guide the development of the technology.

The device envisioned as health care robot is a small mobile platform equipped with a manipulator arm, a vision system, and a user interface. The mobile platform with its sensor systems is manufactured by RWI, and the manipulator arm and the user interface are designed and built by JPL.

In the following section, we will first review the overall architecture of the health care robot, and then describe the main features of the user interface in Section 4. The interactive evaluation methodology is described in Section 5, together with some preliminary results of the users evaluation of the system. We conclude the paper with a brief discussion of this approach and with our plans for future research and development.

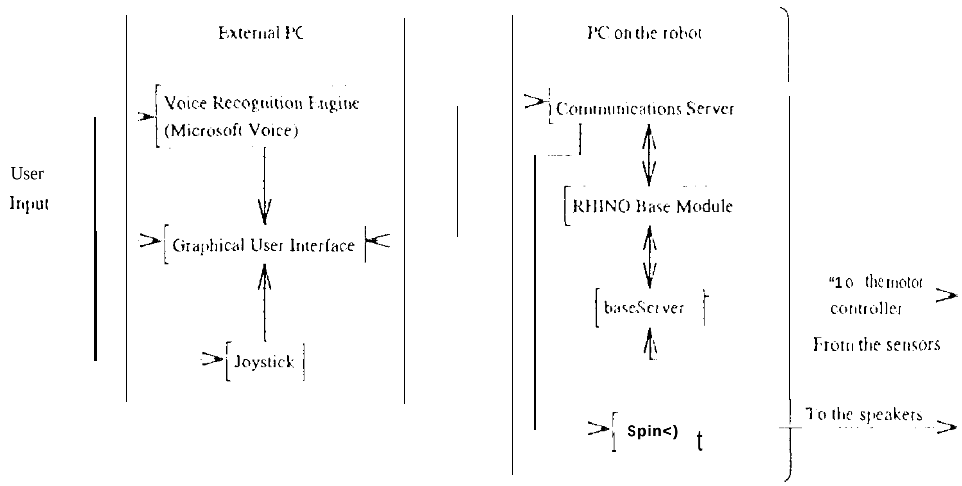

Figure 2: Health Care Robot system architecture

3 System Overview

The complete prototype of the Health Care Robot (HCR) system is shown in Figure 1, and consists of a mobile robotic platform manufactured by RWI, and an IBM-compatible personal computer (PC) serving as a control station, and running the Windows95 operating system, for compatibility with commercial products. The robot is controlled by an internal PC using the Linux operating system.

The robot is a B21 RWI mobile platform, equipped with a color camera mounted on a pan-tilt head, and an array of ultrasound, infrared and contact sensors for autonomous navigation. The robot is powered by four lead-acid batteries providing 6 hours of operation [13].

Two layers of application programs control the motion and the input-output data on the robot. The lower level is called the Base Server, and consists of a collection of device drivers supplied by RWI performing low-level motion control and sensor data acquisition. The second layer is the Rhino package [1] (developed at the University of Bonn (Germany), and providing high-level trajectory control and obstacle avoidance capabilities. Rhino accepts messages from other programs and from external sources. Depending on the message type and on its parameters, Rhino sends a command to the Base server which then executes it.

A communication server handles all communication between the Rhino package and the control station. This program is necessary to ensure compatibility between Rhino and Windows95, since Rhino uses the interprocess communication system TCX [7], which is incompatible with Windows95. The overall structure of the software architecture is shown Figure 2.

The first phase of the project described here focussed on the development of a set of tools for the user interface with the objective of enabling early testing of the Health Care Robot by its future users. This software is described next.

4 The User Interface

The user interface for the Health Care Robot displays the data collected by the robot and accepts different types of user commands. Data from the robot include video images from the robot-mounted camera, sonars readings, position of the robot on a map of the environment, and voice signals. In addition, the interface can display images from other sources, such as a remote physician or a relative, connected via video conferencing.

The data-entry portion of the Graphical User Interface is shown in Figure 3, and consists of five components: voice interface, velocity control, status indicator, sonar display, and alternate motion control.

Currently, the two main modes for controlling the robot motion are voice commands, such as *Rotate Right* and *Move Forward*, and joystick, selectable by checking the *Use Joystick* check box.

For the elderly and the handicapped, keyboard and mouse may present a difficult problem. Voice input as the main control modality offers several advantages: (*i*) it is a natural means of communication, (*ii*) in certain cases of disability, it is the only channel available, (*iii*) it requires no physical linkage, and (*iv*) it can be readily optimized to the user's personal needs.

For people with reasonable manual control, a joystick represents a good alternative to voice commands. The motion control is aided by the video feedback from the robot camera, which always points towards the direction of motion. The user has a direct view of the environment in front of the robot, and a good perception of the possible obstacles.

Additional methods for commanding the robot will become more important when map registration and self-localization capabilities will be available. For example, a map of the environment showing the location of the robot will allow the user to specify the target position with the mouse, relying on the robot to autonomously plan and execute the trajectory. A target can also be specified by voice commands, such as *Go to the kitchen.*

The following sections give a more detailed description of the components of the user interface.

4.1 Feedback to the User

The main source of information about the environment surrounding the robot is the output of the color camera installed on the robot. We are currently experimenting with two methods for sending images in real-time from the robot to the control station. The first method uses the eXceed package [11] for creating an X client on the control station to display the camera images. Since images are transmitted without any compression, this method provides only sub-Hertz refresh rate. We are also experimenting with the *Vic* video-conferencing software [12] which uses the Intra-H.261 compression scheme, and achieves refresh rates of up to 30 frames per second.

A second type of environment feedback is provided by displaying the robots position on a model of the environment. Currently this representation shows a map of the laboratory room where this project is being developed.

The robot's sonar readings are displayed on a separate window as rays emanating from a circle representing the robot. The length of each ray represents the distance measured by the corresponding sonar. Longer lines represent sonar readings of distant objects, whereas shorter lines represent objects close to the robot. Sonar readings are currently used by Rhino for obstacle avoidance, and will be used in the future for environment mapping. New sonar readings are sent by the robot at intervals of about one second.

After receiving a voice command, the robot repeats the command back to the user to confirm the command. The message to be spoken is determined by

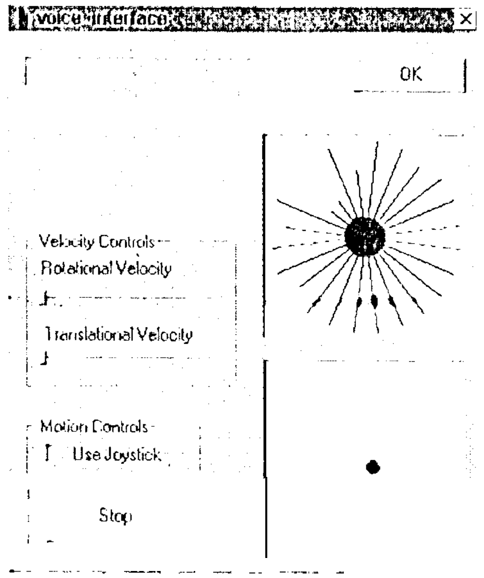

Figure 3: Health Care Robot Graphical User Interface.

the voice interface, which then sends a text string corresponding to the command to the speech server located on the robot. The speech server converts the text string into a voice feedback to the user.

Finally, the last information provided by the user interface is the status indicator, consisting of a text field describing the current robot action. When the interface is in voice control mode, the status indicator shows the command presently being executed. When the interface is in the joystick mode, the status indicator displays joystick control.

4.2 Voice Commands

The main command mode is the voice interface, whose core is a *voice recognition engine*, carrying out the interpretation of the user's utterances. In this phase of the project we are experimenting with Microsoft Voice, a commercial speech recognition software. This program listens for voice input from the user, and tries to match it with one of the commands defined in the pre-stored active voice menus. If the match is successful, the voice recognition engine calls the HCR system which activates the functions associated to the command.

The voice interface recognizes the following fourteen commands: *Stop, Rotate Left, Rotate Right, Turn Right, Turn Left, Left, Right, Move Forward, Move Backward, Step Forward, Advance* ONE-TO-TEN *meters, Go To Sleep, Ready,* and *Attention.* The Rotate Left, Rotate Right, Move Forward, and Move Backward commands cause the robot to move indefinitely until the Stop command is used. Turn Right and Turn Left turn the robot by 900 while Left and Right turn the robot by 100. Step Forward moves the robot forward half a meter. Advance *one-to-ten* meters includes an integer number from one to ten, and moves the robot that many meters forward.

The Go To Sleep, Ready, and Attention commands allow the user to disable and enable the voice recognition system to prevent ordinary conversation to be mistaken for commands. Go To Sleep *disables* the voice recognition. Actually, the voice recognition is not disabled, but it will only respond to the Ready command when it is in *sleeping* state. The Ready and Attention commands provide a two level enablement procedure. Two levels are used for safety. If the Ready command is heard while the robot is in the sleeping state, then the robot listens for the Attention command. If the Attention command is then heard, then voice recognition is enabled, but the robot returns to the sleeping state if nothing else is heard. This helps preventing the voice recognition system from becoming enabled accidentally during normal conversation.

4.3 Joystick Commands

Joysticks are common control devices for motorized wheel chairs, and we included this control method in the HCR interface to capitalize on possible user's skills. The result is a *virtual wheelchair* behavior, which replaces the user's direct view of the environment with the images feel back by the robot camera.

The interface can be switched between voice and joystick command mode by clicking a graphical button on the screen. The joystick has four degrees of freedom, and we use two for controlling the robot, and one for setting the robot velocity. We mapped the forward-backward motion of the joystick to the forward-backward motion of the robot, and the side-to-side motion of the joystick to the rotation of the robot. This because the robot always rotates in place to face the direction of motion before start moving. To move the robot on a diagonal, first the joystick is moved sideways to rotate the robot until it faces the desired rotation, and then the joystick is pushed forward to initiate the motion.

The joystick is also equipped with several buttons and switches, with which we plan to control the pan and tilt unit for the robot camera, and the manipulator arm.

4.4 Mouse Commands

This command mode is reserved for parameter setting, emergency stop, and map-based position commands. Two graphical slide-ham are included in the user interface to set the rotational and translational velocities of the robot. When the interface is in voice mode, the sliders can be operated with the computer mouse.

The graphical *Stop* button halts all movement of the robot, regardless of its current command mode. It provides the control station with the same emergency stop capability provided by the emergency switches installed on the robot.

Map-based position commands are initiated by positioning the screen cursor in the window displaying the map of the environment. The position of the cursor becomes the robot target. By clicking the mouse button the user can command the robot to reach the target. During motion, the robot autonomously avoids the obstacles on its trajectory.

5 The Evaluation Methodology

The approach taken in developing the Health Care Robot emphasizes users involvement from the early design phases. Relevant information about tasks rating is available in the literature [4], but there is no clear understanding of the features of a robotic device designed to accomplish the selected tasks. A *needs assessment* phase is then carried out in parallel to the robot design to guide in selecting the robotic features, and in setting the performance goals. This assessment consists of identifying groups of potential users, including administrators, medical personnel and end-users, and in developing and administering questionnaires for needs assessment and tasks definition.

The procedure used in the assessment follows an Interactive Evaluation Model [5], and consists of the simultaneous investigation of both machine and human performance within a defined environment. The illterac.Live nature of this procedure helps in determining desirable and feasible characteristics of the complete *human-robot* system. The evaluation is carried out while pursuing specific tasks, and it will identify the effective performance of the system, develop appropriate training protocols, assess the users' new capabilities, and provide feedback to the designers.

The first phase of the evaluation consisted in developing a presentation on health care robotics, and administering a questionnaire to the personnel of a long term care nursing and rehabilitation facility in

Southern California [3]. The participants to the survey included the Directors of Rehabilitation, Physical Therapy and Speech Pathology, nurses and aides, for a total of 25 people, of which 16 were female and 9 male. The presentation consisted of slides and videos of past and present applications of robots in health care, and in giving a demonstration of the HCR system. The questionnaire addressed the participants' perception of robots, their attitude towards accepting robots in the facility, and their perception of useful robotic tasks in their facility.

The questionnaire included statements such as: *robots are too complicated for me to understand*, and *a robot would be useful in my job*. The participants were asked to rank their agreement to the statements on a scale 1 to 6, and to select adjectives out of a prepared list, which would best describe their feelings about robots. The task definition of the questionnaire asked the participants to identify relevant tasks for a one-armed robot, and to prioritize the tasks using a scale of 1 through 6. A preliminary evaluation of the responses to the questionnaire indicates that the top two rated tasks are specific to patients care, such as pouring liquids, assistance with feeding, and retrieval tasks. Task more relevant to staff activities were ranked 3 through 6, including folding linens, transporting meal trays, and assisting in patient security.

6 Conclusions

This paper presents a progress report on our current work on mobile robots for the assistance to the elderly and the handicapped. We combined a mobile robotic platform with a personal computer, and developed a low-cost control station for operating the robot. The control station is capable of interpreting voice, joystick, and mouse commands, and displays real-time images from the robot camera, a schematic map of the environment, and the reading of the robot ultrasonic sensors.

The proposed system responds to the needs of the health care community for a low-cost robotic aid which could perform simple home assistance functions, and selected tasks in medical facilities. We are currently in the process of evaluating the utility of the system and the accessibility of the control station with potential users of the robot, including administrators, medical personnel, and patients.

In the future, we plan to add more powerful input-output capabilities to the user interface, and to equip the mobile robot with an articulated manipulator, currently under development, for executing simple fetch-and-carry tasks.

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